Compact 6-DOF Stage for Optical Adjustments

Adjustments can be made in all translational and rotational degrees of freedom.

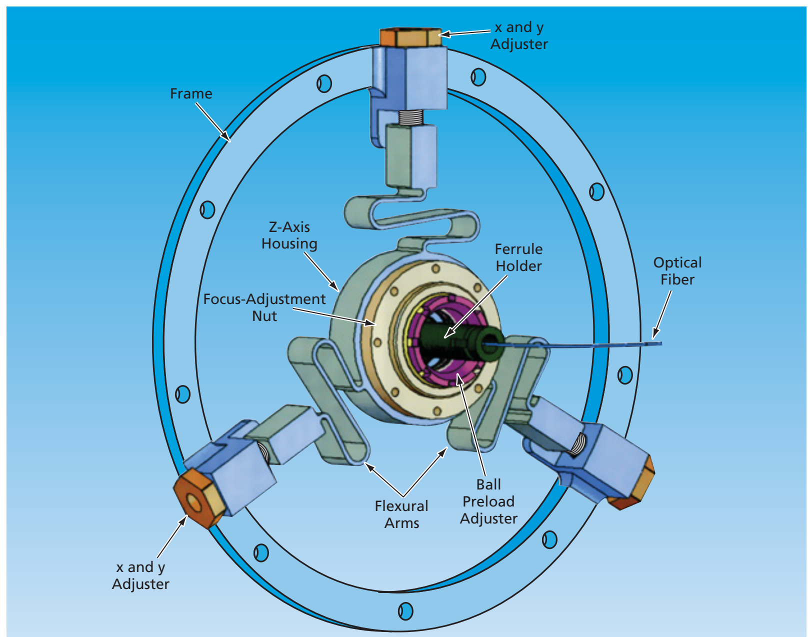
NASA's Jet Propulsion Laboratory, Pasadena, California

The figure depicts selected aspects of a six-degree-of-freedom (6-DOF) stage for mechanical adjustment of an optical component. The six degrees of freedom are translations along the Cartesian axes (x, y, and z) and rotations about these axes (θ_x, θ_y, and θ_z, respectively). Relative to prior such stages, this stage offers advantages of compactness, stability, and robustness, plus other advantages as described below.

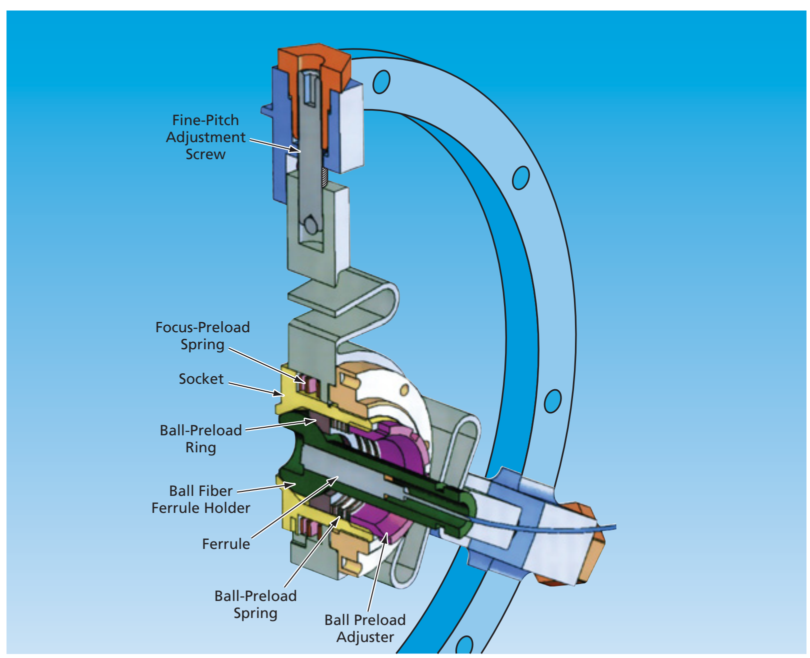
The stage was designed specifically as part of a laser velocimeter and altimeter in which light reflected by a distant object is collected by a Cassegrainian telescope and focused into a single-mode, polarization-maintaining optical fiber. The stage is used to position and orient the input end of the optical fiber with respect to the focal point of the telescope. Stages like this one can also be adapted for use in positioning and orienting other optical components, including lenses, prisms, apertures, and photodetectors.

The optical fiber or other optical component is mounted in a ferrule that is, in turn, mounted in a ferrule holder that is an extension of the ball part of a ball-and-socket assembly that enables adjustment in all three rotational degrees of freedom. The position of the ferrule within the ferrule holder is set so that the center of the input face of the optical component lies at the center of the ball. As a result of this setting, rotational adjustment is not accompanied by undesired translational adjustment.

The subassembly comprising the ball, ferrule holder, and optical component is spring-loaded into the socket, and the spring load can be adjusted by means of a threaded ball-preload adjuster. The ferrule holder and the ball-preload adjuster are equipped with external surfaces that mate with special-purpose adjustment tools. The spring load is chosen to make the frictional torque between the ball and the socket small enough that rotational adjustments can be made, yet large enough that the ball and socket retain their relative angular position once the angular adjustment



6-DOF STAGE AS FULLY ASSEMBLED



CUTAWAY VIEW OF 6-DOF STAGE

This **Compact Assembly** enables stable adjustment of the input end of the optical fiber in all three translational and all three rotational degrees of freedom. Rotational adjustments can be made without causing undesired translations, and translational adjustments can be made without causing undesired rotations.

has been completed and the rotational-adjustment tools removed.

Optionally, the ball-and-socket assembly as described thus far could be used alone as a rotation-only stage. However, in the original application, the ball-and-socket assembly is mounted within a *z*-axis housing that, as its name suggests, enables translational adjustment along the *z* axis (focus adjustment). The socket is in threaded engagement with a focus-adjustment nut that can be turned about the *z* axis to make the adjustment. An anti-rotation pin that is free to translate along a *z*-oriented slot prevents undesired rotation of the socket about the *z* axis during focus adjustment. A focus-preload spring exerts a *z*-axis preload between the socket and the *z*-axis housing to prevent backlash in the focus adjustment.

Optionally, the *z*-axis-adjusting mechanism as described above could be used alone as a *z*-axis-translation stage. However, in the original application, it is mounted in an *x*–*y* translation stage that includes three flexural arms positioned at equal angular intervals on a circular frame. The radial position of the outer end of each flexural arm can be varied by means of a fine-pitch adjustment screw. Initially, all three adjustment screws are set at approximately the midpoints of their ranges, thereby placing all three flexural arms in tension and approximately centering the *z*-axis housing in the circle. Thereafter, the screws are turned, singly or in pairs as needed, to make fine adjustments to bring the optical component into *x* and *y* alignment. Care must be taken during these adjustments to maintain all three flexural arms in tension so as to prevent backlash. The *x*–*y* adjustment resolution is much finer than the thread pitch of the adjustment screws. Optionally, like the rotational and *z*-axis sub-stages, the *x*–*y* stage could be used by itself.

This work was done by Syed Shafaat and Daniel Chang of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). ***NPO-45273***

Ultrasonic/Sonic Impacting Penetrators

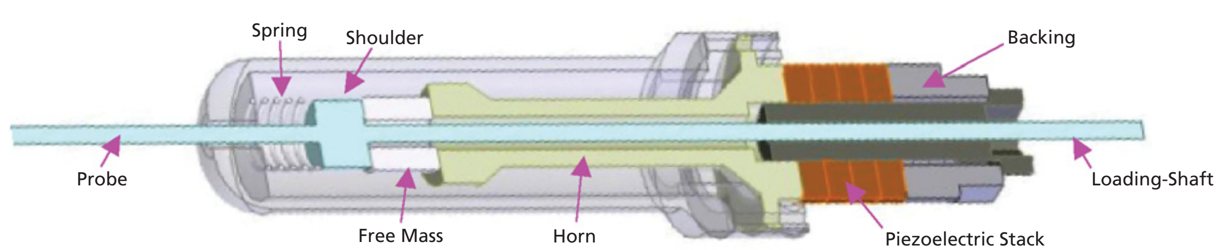
Soil can be probed relatively gently to a depth of several feet.

NASA's Jet Propulsion Laboratory, Pasadena, California

Ultrasonic/sonic impacting penetrators (USIPs) are recent additions to the series of apparatuses based on ultrasonic/sonic drill corers (USDCs). A USIP enables a rod probe to penetrate packed soil or another substance of similar consistency, without need to apply a large axial force that could result in buckling of the probe or in damage to some buried objects. USIPs were conceived for use in probing and analyzing soil to depths of tens of centimeters in the vicinity of buried barrels containing toxic waste, without causing rupture of the barrels. USIPs could also be used for other purposes, including, for example, searching for pipes, barrels, or other hard objects buried in soil; and detecting land mines.

USDCs and other apparatuses based on USDCs have been described in numerous previous *NASA Tech Briefs* articles. The ones reported previously were designed, variously, for boring into, and/or acquiring samples of, rock or other hard, brittle materials of geological interest. To recapitulate: A USDC can be characterized as a lightweight, low-power, piezoelectrically driven jackhammer in which ultrasonic and sonic vibrations are generated and coupled to a tool bit. As shown in the figure, a basic USDC includes a piezoelectric stack, a backing and a horn connected to the stack, a free mass ("free" in the sense that it can slide axially a short distance between the horn and the shoulder of tool bit), and a tool bit, i.e., probe for USIP. The piezoelectric stack is driven at the resonance frequency of the stack/horn/backing assembly to create ultrasonic vibrations that are mechanically amplified by the horn. To prevent fracture during operation, the piezoelectric stack is held in compression by a bolt. The bouncing of the free mass between the horn and the tool bit at sonic frequencies generates hammering actions to the bit that are more effective for drilling than is the micro-hammering action of ultrasonic vibrations in ordinary ultrasonic drills. The hammering actions are so effective that the axial force needed to make the tool bit advance into the material of interest is much smaller than in ordinary twist drilling, ultrasonic drilling, or ordinary steady pushing.

The differences between a USIP and a USDC-based apparatus described above lie in design details that make a USIP more suitable for penetrating packed soil. The piezoelectric stack in an experimental prototype USIP had a diameter of 1.0 in. (≈25 mm) and could be made to resonate at a frequency between 12 and 20 kHz, the exact value depending on the



The design of **Prototype USIP** shows key components.